CARBON EMISSIONS FROM SPRING 1998 FIRES IN TROPICAL MEXICO

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ABSTRACT

We used NOAA-AVHRR satellite imagery, biomass density maps, fuel consumption estimates, and a carbon emission factor to estimate the total carbon (C) emissions from the spring 1998 fires in tropical Mexico. All eight states in southeast Mexico were affected by the wildfires, although the activity was concentrated near the common border of Oaxaca, Chiapas, and Veracruz. The fires burned approximately 482,000 ha and the land use/land cover classes most extensively impacted were the tall/medium *selvas* (tropical evergreen forests), open/fragmented forests, and perturbed areas. The total prompt emissions were 4.6 TgC during the two-month period of our study, contributing an additional 24% to the region's average annual net C emissions from forestry and land-use change. Mexico in 1998 experienced its driest spring since 1941, setting the stage for the widespread burning. If fire episodes such as the one that occurred in Mexico and around the world become the norm due to warmer and drier conditions, then an increase in C emissions may represent a significant positive feedback to global climate change.

Keywords: Wildfires, Tropics, Carbon Emissions, biomass, Mexico.

INTRODUCTION

Deforestation and biomass burning activities lead to major carbon (C) emissions to the atmosphere (Crutzen and Andreae 1990). Tropical biomass burned in the late 1970s has been estimated at 5.4 Pg/yr (Pg = pentagram = 10^{15} g), including 1.8 Pg/yr from deforestation and shifting cultivation (Hao and Liu 1994). This burning has been estimated to contribute 2.4 PgC/yr to the atmosphere, or 30% of the total from all sources (Schneider 1996). Houghton (1991) asserts that, because estimates of C emitted from biomass burning do not include eventual decomposition of biomass following deforestation, nor oxidation of wood products and soil carbon, clearing and burning of biomass associated with shifting cultivation and deforestation represents only 40-60% of the net C flux from land use/ land cover (LU/LC) change. Conversely, pyrogenic formation of long-lived elemental C and forest regrowth both produce C uptake by the terrestrial biosphere. Wildfires in tropical latitudes are usually discounted in global biomass burning computations because conditions are considered too moist for fires to spread from activities such as shifting cultivation (e.g., Hao and Liu 1994). Thus, it is highly desirable to advance our understanding of the magnitude and effects of these activities.

Recent wildfires in Florida, Central and South America, Canada, Russia, Spain, Indonesia, Greece, and Mexico have been attributed to the latest El Niño phenomenon.

Such fires contribute to the annual emissions of the greenhouse gases CO_2 and CH_4, as well as CO and other hydrocarbons and particulate matter, from routine burning of savannas, agricultural wastes, and fuelwood/charcoal, as well as prescribed burns, shifting cultivation, and land-use change. If global climate is becoming warmer and drier because of emissions of greenhouse gases, a higher incidence of wildfires would be a logical consequence (Cofer et al. 1991). Increased fire hazard indices due to increasing mean temperatures and decreasing mean humidity have been computed for temperate and boreal countries (Pinol et al 1998; Stocks et al 1998). If tropical fire frequency is increasing because of the near-term effects of El Niño events or because of long-term climate change, global emission projections of greenhouse gases may need to be adjusted accordingly.

An El Niño/La Niña combination of high rainfall in 1997 followed by record drought during the first five months of 1998 in Mexico was only the second such phenomenon observed in the past 25 years (SEMARNAP 1998). Average rainfall of 55 mm for the January through May 1998 period compared to a mean rainfall of 119 mm for the five-month period and the previous low of 69 mm for the period since 1941. These conditions set the stage for a potentially severe fire season. For the years 1980-1997, the country of Mexico averaged 6,837 fires that burned 223,114 ha (SEMARNAP 1998). During just three months of 1998, imagery from NOAA satellites documented more than 10,000 fires burning more than 400,000 ha of land in tropical Mexico (Lyons et al. 1998; NASA 1998; Steitz and Kenitzer 1998; U. S. AID 1998; USDA Forest Service 1998).

Prompt, or transitory, C emissions are defined as those resulting from burning of savannas, fuelwood, agricultural wastes, and wildfires, in which the emitted C will be returned to the biosphere by vegetation regrowth within a few years. Prompt emissions are contrasted with net emissions, resulting from permanent LU/LC conversions and the subsequent decomposition/oxidation of woody debris, soil organic matter, and wood products, as well as the counterbalancing effect of vegetation regrowth. It is reported that 33-50% of prompt C emissions from global biomass burning can be considered net emissions (Crutzen et al. 1990). The objective of this paper is to quantify the total prompt C emissions from 1998 fires in southeast Mexico (Figure 1), an example from a region in the developing tropics, where 87% of all biomass burning occurs (Andreae 1991) and to speculate on potential changes in net C emissions.

Figure 1. Study area in tropical Mexico showing location of the eight states.

METHODS

We reviewed AVHRR satellite imagery of Mexico published on a NOAA Worldwide Web site (Operational Significant Event Imagery http://www.osei.noaa.gov/Events/Fires/Mexico) and retrieved those images that appeared suitable. Selection criteria included having a large preponderance of clear sky, good location definition of either state boundaries or latitude-longitude grids for registration of images, clear illumination of fire hot spots, and temporal coverage of the most active fire activity, from mid-April to mid-June 1998. We used the imagery to identify the areas impacted by wildfires in the eight-state southeast Mexico region.

Eight images were selected (April 16, May 12, 17, 18, and 25, June 5, 15, and 22) during the peak of the fire episode to identify approximately 486,000 ha subject to fires. The images were registered to a Mexican boundary coverage and rectified in our GIS. The rectified images were converted into a raster grid dataset and the area values of the fire hot spots were quantified. The fire hot spots were then selected and converted into polygon coverage. The polygon coverage was reviewed for fair representation of the original image (hot spots, no clouds, and good registration with boundaries). The image was then projected into a Lambert map coordinate system and the individual coverages were joined into a single coverage.

The polygon coverage was used to clip data from the Inventario Nacional Forestal Periodico de Mexico (INFP) (SARH 1994) and the state boundaries were overlaid on the clipped dataset. The area of each LU/LC class was identified. Characteristic aboveground biomass densities of the various LU/LC classes were calculated in a previous study (Cairns et al., submitted). Briefly, biomass densities were modeled with field measured tree dimensions (heights and diameters) from the INFP, mean annual precipitation, tree type, wood densities, and published allometric equations (Brown 1997). Measurements of approximately 95,000 trees in more than 5,200 field plots (0.1 ha) were used to compute biomass densities. The total area per class burned in each state was then calculated.

Quantities of biomass burned (M, in Mg) in each LU/LC class were calculated from the equation (Hao and Liu 1994) **M = A x B x** α. A is the area of fire burned (ha), B is aboveground biomass density (Mg/ha), and α is proportion of aboveground biomass burned [0.25 for closed forests, tall/medium and short *selvas* (tropical evergreen forests), fragmented forests and *selvas*, and forest plantation classes; 0.45 for open forests; and 0.81 for all other LU/LC classes]. A low α was used for most forests because it was assumed that forest fires consumed only understory vegetation, although widespread tree mortality has been observed in the field the year following such fires (Roberto Martinez Dominguez, SEMARNAP, personal communication). Our α value for closed forests, tall/medium and short *selvas*, fragmented forests and *selvas*, and forest plantations is similar to that used by others (Seiler and Crutzen 1980; Ward et al 1976). An emission factor (0.5 MgC/Mg biomass) was applied to account for the sum of all C compounds (Susott et al. 1996). The total regional C emissions were then calculated as the sum of the emissions from all LU/LC classes in our study region affected by fires.

RESULTS AND DISCUSSION

Map plots derived from the eight AVHRR images show a concentration of fires near the common border of Veracruz, Oaxaca and Chiapas, as well as numerous fires in the Yucatan peninsula (Figure 2). When the fires were overlaid on the LU/LC map, we saw that 18 different classes were variously impacted (Table 1). The LU/LC classes that were most heavily impacted by wildfires were tall/medium *selva* (107,000 ha), fragmented forest and *selvas* (102,000 ha), and perturbed areas (95,000 ha). Other classes impacted to a lesser extent included pasture-grasslands (49,000 ha), cultivated land (41,000 ha), and short *selva* (20,000 ha). The AVHRR imagery indicated that 92% of the area burned was concentrated in the 24-day period between May 12 and June 5 (Figure 2).

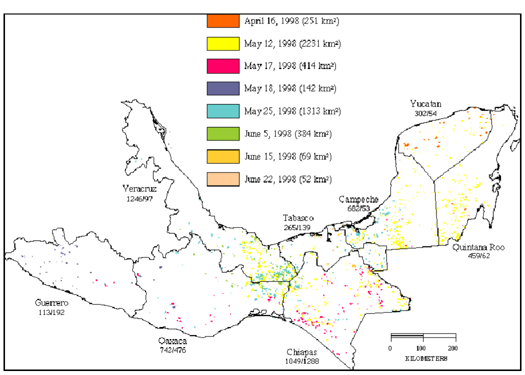

Figure 2. Location, timing, and extent of Spring 1998 fires derived from NOAA-AVHRR satellite imagery.

The total prompt emissions from 1998 Spring wildfires in tropical Mexico were approximately 4.6 TgC (Tg = teragram = 10^{12} g) (Table 1). This equals a 24% addition to the mean annual net C emissions of 19.2 Tg from LU/LC change in tropical Mexico (Cairns et al., submitted). This tropical fire C emission also equals 9% of Mexico's total annual C emissions from forestry and land use (Masera et al. 1997) as well as 5% of Mexico's total annual C emissions from fossil fuel use (Mendoza et al. 1991). Because of their relatively high biomass densities and the wide area extent of their fires, tall/medium *selva* was the largest single source of C emissions (1.8 Tg, 40% of total C emissions), followed by perturbed areas (0.8 Tg), closed forest (0.5 Tg), pasture/grasslands (0.5 Tg), and fragmented forest and *selvas* (0.4 Tg). Smaller quantities of C were emitted from fires in short *selva* (0.2 Tg), cultivated land (0.2 Tg), and open forests (0.2 Tg). Because of their low aboveground biomass densities, cultivated lands were a lesser source of C emissions, despite their relatively large area burned. However, perturbed areas are, by definition, lands that were previously forested but are now either pasture or cultivated land (SARH 1994). Thus, fires in all agroecosystems emitted a total of 1.5 TgC, or one-third of the total C emissions.

AVHRR imagery has been shown appropriate for the purpose for which it was used in this study. Such imagery was used for the large 1987 wildfires in China and the former USSR to quantify spatial and temporal distribution of fire occurrence, and was combined with biomass densities to estimate greenhouse gas emissions (Cahoon et al. 1991; Levine et al. 1991). AVHRR-LAC imagery, with a nominal spatial resolution of 1.1 km x 1.1 km, like we employed in this study, is reported to be suitable for such purposes (Brustet et al. 1991).

This dataset should not be viewed as an exact mapping of the 1998 Mexican fires, but rather as a representation of the areas in which the fires burned and a first approximation of the extent of those fires in the

LU/LC Class	States[a]	ABD Mg/ha	Area burned ha	C emissions[b] MgC
Cultivated land	yu/ch/oa/ve	11.6	38,320	180,027
	qr/ca/ta/gu	16.4	2,820	18,730
Pasture/grasslands	yu/ch/ca/oa/qr	21.2	25,883	222,231
	ve/ta/gu	26.6	23,376	251,830
Closed cloud forest	all	126.6	11,589	183,396
Open cloud forest[c]	all	33.1	2,785	20,741
Closed oak forest	ch/gu	57.9	448	3,242
	oa/ve/ta	87.5	127	1,389
Open oak forest[c]	all	33.1	3,279	24,420
Closed pine forest	all	152.1	8,036	152,784
Open pine forest[d]	ch/ve	45.2	4,270	43,426
	oa	64.3	1,257	18,186
	gu	77.5	168	2,930
Closed pine/oak forest	ch	52.0	1,862	12,103
	oa/ve/gu	145.3	7,034	127,755
Open pine/oak forest[d]	ch/ver	45.2	3,746	38,097
	oa	64.3	2,395	34,650
	gu	77.5	442	7,707
Frag. forest and *selvas*[c]	all	33.1	101,999	422,021
Tall/medium *selva*	gu	33.8	249	1,052
	qr/yu/ch/ca/oa/ta	111.2	81,440	1,132,016
	ve	225.8	25,197	711,185
Short *selva*	ch/oa/ve/ta/gu	26.0	1,994	6,481
	qr/yu/ca	71.2	18,029	160,458
Perturbed areas	qr/ch/ca/oa/ta	18.0	61,900	451,251
	yu/ve/gu	25.6	33,556	347,909
Agricultural plantations	all	31.4	1,081	13,747
Forest plantations	all	90.7	1	11
Chaparral	qr/ch/ca/oa/ve	11.8	59	282
Other		0.0	19,124	0
Water Bodies		0.0	3,167	0
TOTALS:			485,633	4,590,058

[a] ca = Campeche, ch = Chiapas, gu = Guerrero, oa = Oaxaca, qr = Quintana Roo, ta = Tabasco, ve = Veracruz, yu = Yucatan

[b] C emission factor of 0.5 MgC/Mg biomass was used.

[c] and [d] Class ABDs not statistically different, thus were combined for computations

Table 1. Tropical Mexico fire carbon (C) emissions derived from aboveground biomass densities (ABD) and areas burned in each land use/land cover (LU/LC) class.

LU/LC classes over which they burned. As with savanna, fuel wood, and agricultural waste biomass burning, total C emissions from wildfires are assumed to represent prompt, rather than net, emissions because it is assumed that the vegetation burned will soon regrow and accumulate C in terrestrial systems. Our estimate of 4.6 TgC from the Mexican fires is assumed to represent prompt emissions because it is reported that vegetation regrows rapidly following such fires (SEMARNAP 1998). However, the possibility that trees impacted by these fires eventually suffer nearly complete mortality (Roberto Martinez Dominguez, SEMARNAP, personal communication) means that some the C emissions may be considered net releases.

SEMARNAP reported 236,040 ha burned in the eight tropical states of Mexico from the beginning of 1998 through August 12 (Figure 2) by compiling ground-based observation reports from state government forestry departments. This compares to our estimate, derived from satellite imagery, of 485,633 ha between April 16 and June 22. Our estimate should be reduced by the 3,167 ha of fires that appeared to be located over water bodies. In addition, our estimate included 19,124 ha in the ‘other’ LU/LC class for which no biomass densities were available, but where they are assumed small. This class includes smaller sub-classes such as mangroves, coastal dunes, palms, gallery vegetation, and areas without apparent vegetation. Removing water and ‘other’ areas brings our estimate down to 463,342 ha, but does not alter the C emission estimate. Differences in areas burned may be attributed to reporting procedures used by Mexican agencies (Roberto Martinez Dominguez, SEMARNAP, personal communication).

Uncertainties affecting the accuracy of our estimated C emissions involve the issue of crown versus ground fires mentioned previously. The March Mexican rainfall was 13% drier than normal; April 68% drier; and May 80% drier (SEMARNAP 1998). Under these record extreme conditions, the assumption that crowns did not burn, or that rapid regrowth will occur, may be questioned. If it is assumed that more than understory vegetation burned and a higher value for the proportion of aboveground biomass burned, $\alpha = 0.40$ (Fearnside 1990; Ward et al. 1992), is used for closed forests, tall/medium and short *selvas*, fragmented forests and *selvas*, and forest plantation classes, then the total C emissions would increase 37%. The value we used, ? = 0.25, is lower than that reported by Fearnside (1990) and Ward et al. (1992), but higher than the $\alpha = 0.20$ reported for temperate and boreal forest fires (Seiler and Crutzen 1980). The proportions of aboveground biomass burned, $\alpha = 0.45$ for open forests and 0.81 for all other LU/LC classes, were consistent with Kauffman and Uhl (1990) and Menaut et al. (1991), respectively.

Estimates of the area burned are influenced by the nature of the NOAA-AVHRR imagery, which has its highest spatial resolution of 1.21 km^2 (pixel size at nadir). At this resolution, small fires may be missed, increasing area uncertainty (Cahoon et al. 1991). Conversely, small fires may saturate a particular pixel, overestimating the area burned. Global biomass burning in general is not well quantified as to area burned, proportion of biomass consumed per unit area, nor the chemical and physical properties of the fuels consumed (Radke et al 1991). Other uncertainties may be related to burning efficiencies, which are dependent on water content of the organic material and the proportion of live to dead biomass (Menaut et al 1991).

The global biomass burning literature usually discounts the contribution of tropical forest wildfires because it is assumed that those forests are too moist to allow the propagation of wildfires (Andreae 1991). However, during the spring 1998 wildfires in tropical Mexico, 45% of the C emissions were from wildfires in tall/medium (1.8 TgC) and short (0.2 TgC) tropical forests (*selvas*).

We assume that wildfires originating from shifting cultivation in tropical forests were able to spread because the weather was drier than normal and fire suppression efforts were hindered by inaccessibility. Similar fire events may be expected more frequently in the future if global change results in a warmer and drier climate. New model predictions indicate that a decrease in effective precipitation (mean precipitation - mean evaporation) and an increase in cloud-to-ground lightning frequency resulting from a $2XCO_2$ scenario will interact with an increase in anthropogenic fires from high population densities and a predicted increased frequency of the cyclonic storms common to this area during the next 50-100 years (Goldammer and Price 1998). The net combination of these predicted phenomena will likely be more frequent incidence of fires and a trend toward low-biomass-density LU/LC distributions and less C stored in terrestrial biomass. In this way, higher net C emissions to the atmosphere may become the norm, rather than the prompt, temporary emissions usually attributed to wildfires.

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